There is no drawing corresponding to Figure 1-12 in this report;

the complete drawings for the report are therefore numbered

Figure 1-1 through Figure 1-11 and Figure 1-13 through Figure 1-15.

~~SECRET~~
CONFIDENTIAL

Series A
Copy 1 of 4 copies
This document consists of
35 pages

FIRST QUARTERLY PROGRESS REPORT

PROJECT 8006

12 March 1958 - 21 August 1958

Prepared by
Charles Zucker

Approved by
Dr. Stanley Grand

25X1

CONFIDENTIAL

RADIATION RESEARCH CORPORATION
1114 First Avenue
New York 21, New York

~~SECRET~~

~~SECRET~~

CONFIDENTIAL

TABLE OF CONTENTS

		Page
I.	PURPOSE	2
II.	ABSTRACT	2
III.	BACKGROUND	3
IV.	DISCUSSION OF BATTERY DESIGNS	3
	A. Vacuum Dielectric Battery	3
	B. Solid Dielectric Battery with Solid Source	4
	C. Solid Dielectric Battery with Gaseous Source	5
	D. Theory of Operation of Radioactive Batteries	5
	E. Specific Designs	8
	1. Vacuum Tritium Battery	9
	2. Solid Dielectric Tritium Battery	10
	3. Vacuum Nickel Battery	11
	4. Solid Dielectric Krypton Battery	12
	5. Solid Dielectric Promethium Battery	14
	6. Solid Dielectric Thulium Battery	15
V.	EXPERIMENTAL	17
VI.	PROPOSED FUTURE PROGRAM	19
	A. Dielectric Studies	19
	B. Thulium Battery	20
	C. Voltage Transformer	20

CONFIDENTIAL

~~SECRET~~

I. PURPOSE

To conduct research investigations on the utilization of radioactive energy as a source of electrical energy for use in a portable power source. Efforts will be directed towards power sources having the following characteristics:

A. General Requirements:

1. operate for a period of more than one year
2. operate throughout the temperature range from -65° to + 165°F

B. Specific Requirements:

1. the volume should be ~~one cubic foot~~ or less 6" cube
2. the power delivered should be 0.1 watt (continuous delivery)
3. the power source should weigh no more than ~~thirty~~ 10 pounds
4. the external radiation should be limited to as low a value as is possible

II. ABSTRACT

Various radioactive materials were considered aspossible primary sources of energy for the 0.1 watt electrical source. Those offering the most promising results were: promethium, tritium, krypton, nickel and thulium. The structural designs of different batteries were considered in some detail. The relevant parameters for the different isotopes and battery types were calculated.

A krypton battery was built to determine reliability and obtain information which could be extrapolated to systems within the scope of this project. Numerous tests and techniques were developed in this undertaking and experimental measurements are being continued.

III. BACKGROUND

The use of radioactivity in generating energy has been studied by various authors. Different methods of using the energy of the emitted alpha and beta particles (electrons) have been proposed. All of the methods put forth attempt to convert the energies of these particles into useful electrical energy. The inherent power limitations in this type of generator are related to the energy of the emitted particle and the amount of radioactive material used.

The current limitations may be realized when one considers the theoretical maximum current obtainable from a one curie source of beta particles. A one curie beta source emits 3.7×10^{10} particles per second. The maximum current which can be derived from such a source is equal to

$$i_{max} = 3.7 \times 10^{10} \frac{\text{electrons}}{\text{sec}} \times 1.6 \times 10^{-19} = 5.9\ 10^{-9} \text{ amps}$$

However, these materials are capable of producing currents at potentials of thousands of volts. It becomes necessary, therefore, in many applications, to employ a DC to DC transformer for the necessary voltage reduction and current increase.

IV. DISCUSSION OF BATTERY DESIGNS

The batteries considered in this report fall into two categories: vacuum dielectric and solid dielectric. The operation of these two types of radioactive power sources will be discussed so as to illustrate the general principle of their operation.

A. Vacuum Dielectric Battery

This classic battery type was first devised by Moseley (1) and has since been elaborated on by Linder (2) and his co-workers. This battery utilizes an alpha or

(1) H. G. J. Moseley, Proc. Roy. Soc. (London) A88, 471 (1913)

(2) E. G. Linder, S.M. Christian, J. Appl. Phys., 23, 1213 (1952)

beta-emitting source in close proximity to a metal collecter in a vacuum. A general schematic for this type of battery is shown in Figure 1. The maximum useable current obtained from this battery is limited by its source strength, its secondary electron emission characteristics and its leakage resistance. The source assemblyusually consists of a radioactive isotope bonded to a thin sheet of metal. The maximum voltage available is either the maximum energy of the emitted particles or the product of the maximum current times the effective leakage resistance, whichever is smaller.

B. Solid Dielectric Battery With Solid Source

This battery is essentially similar to the battery described above except that the vacuum dielectric is replaced by a solid dielectric.(3). A schematic for this type of battery, using the radioactive beta source described above, is shown in Figure 2.

The principal advantage of the solid dielectric battery is the elimination of the necessity of maintaining a vacuum, thereby increasing reliability and simplifying construction. The maximum current is dependent on the source strength, the spectrum of beta particle energies, the leakage resistance of the terminals, and the conductivity and absorption properties of the dielectric. As the thickness of the dielectric increases, the absorption of the beta particles also increases. There is, however, a higher voltage developed across the thicker dielectric which results in increased voltage efficiency. A compromise must be made between these competing effects.

(3) J. H. Coleman, Nucleonics, 11, No. 12, Pages 42-45 (1953)

C. Solid Dielectric Battery with Gaseous Source

This type of battery is shown schematically in Figure 3. The radioactive gas emits electrons which may ionize the gas or traverse the dielectric. Some of the emitted electrons are scattered by collisions and captured by the dielectric; those electrons which survive constitute the net current produced by the battery. The energetic primary electrons ionize the gas and produce low energy electrons which act as a low resistance path between the residual positive nuclei (from beta decay) and the anode. The advantages of this construction is that the gas can be mechanically constrained by the enclosure thereby eliminating any absorbing element between the source and collector.

D. Theory of Operation of Radioactive Batteries

In studying the operation of radioactive batteries (shown in Figures 1, 2 and 3) certain fundamental mechanisms must be considered. In the vacuum dielectric and gaseous solid dielectric batteries, the secondary electrons from the collector or from the ionized gas, respectively, are attracted to the anode. This flow of electrons acts as a negative current (opposite to the primary current) and tends to reduce the output of the battery. The low energy secondary electrons in the solid source solid dielectric battery are prevented by the dielectric from returning to the source; however conduction electrons in the dielectric do constitute a reverse current.

Let us define the following:

i_o = net primary current (i.e. gross source current less self-absorption)

C = self-capacity of the battery

$R_D(t)$ = leakage resistance of the dielectric

D. Theory of Operation of Radioactive Batteries (Contd)

$R_L(t)$ = leakage resistance of the load (usually a capacitor)

$R_s(t)$ = leakage resistance of the surface

$V(t)$ = operating voltage

If i_o and C are considered constant and the resistances are functions of time, temperature, humidity or voltage, then the general equations describing the action of the battery are:

$$(1)\quad i(t) = i_o \frac{-V(t)}{R_L(t)} \frac{-V(t)}{R_D(t)} \frac{-V(t)}{R_s(t)}$$

$$(2)\quad CV(t) = \int_o^t i(t)dt, \text{ and } V(t) = O \text{ at } t = O$$

where

$i(t)$ = net current minus leakage currents (Equation 1)

$V(t)$ = voltage between source and collector

$q(t)$ = charge stored in the system

The second equation relates the accumulation of charge to the current flowing in the circuit. Substituting equation (2) into equation (1) we obtain

$$(3)\quad i(t) = i_o - \frac{\int_o^t i(t)dt}{C\,R_L(t)} - \frac{\int_o^t i(t)dt}{C\,R_D(t)} - \frac{\int_o^t i(t)dt}{C\,R_s(t)}$$

For an infinite surface resistance (special case) equation 3 becomes

$$(4)\quad i(t) = i_o - \frac{\int_o^t i(t)dt}{C\,R_L(t)} - \frac{\int_o^t i(t)dt}{C\,R_D(t)}$$

or

$$(5)\quad C\,R_L(t)R_D(t)\,i(t) = i_o C\,R_L(t)\,R_D t - R_D(t)\int_o^t i(t)dt - R_L(t)\int_o^t i(t)dt$$

D. Theory of Operation of Radioactive Batteries (Contd)

This is an integral equation and cannot be solved without a knowledge of $R_D(t)$ and $R_L(t)$.

As a special case let

$$R_L(t) = \text{constant} = R_L$$

$$R_D(t) = \text{constant} = R_D$$

In this case equation 5 reduces to

$$(6)\quad CR_DR_L\, i(t) = i_o CR_D R_L - R_D \int_o^t i(t)\,dt - R_L \int_o^t i(t)\,dt$$

or

$$(7)\quad CR_DR_L \frac{di}{dt} = -R_D i(t) - R_L i(t)$$

Inserting the initial condition that

$$i = 0 \text{ at } t = 0$$

into equation 7 we obtain the solution

$$(8)\quad i = i\left(1 - \exp\left(-t \frac{R_D + R_L}{R_D R_L C}\right)\right)$$

The corresponding voltage is given by

$$(9)\quad V = i \frac{R_D R_L}{R_D + R_L}$$

This equation shows that the voltage rises exponentially with a time constant equal to

$$(10)\quad t = \frac{R_D R_L C}{R_D + R_L}$$

and approaches a maximum voltage of

$$(11)\quad V \text{ maximum} = i_o \frac{R_L R_D}{R_L + R_D}$$

From equation 11 it is seen that the maximum voltage is a function of the primary current and the circuit resistances.

E. Specific Battery Designs

The design of a radioactive battery is dependent upon the type of radioactive material used. However, there are certain efficiency factors which must be considered in all designs and these will be discussed in some detail.

The mean energy of the beta particle, E_o, is determined from the beta spectrum of the isotope. A battery operating at a voltage E will have an approximate voltage efficiency

$$e_v = E/E_o = \frac{\text{operating voltage of the battery}}{\text{mean energy of the beta particle}}$$

The radioactive source will also have a current efficiency, e_i, defined by

$$e_i = \text{current efficiency} = i/i_o = \frac{\text{maximum output current from the source}}{\text{total beta current available from the isotope used}}$$

In a vacuum dielectric battery there is also a collection efficiency, usually an empirical number, which will be designated by

$$e_c = \text{collection efficiency} = \frac{\text{total collected current}}{\text{maximum output current from the source}}$$

In a solid dielectric battery the dielectric efficiency is defined as

$$e_d = \text{dielectric efficiency} = 1 - (1/2)\,\frac{\text{absorption thickness of the dielectric}}{\text{mean range of the beta particle}}$$

It is to be noted that the above formulation is approximately true for values of the dielectric absorption thickness less than twice the range of the mean beta particle.

Finally, there is a geometrical efficiency which is defined as

$$e_g = \text{geometrical efficiency} = \frac{\text{total effective collection area/cell}}{\text{total available collection area/cell}}$$

The overall efficiency of the battery is the product of these separate efficiencies, whenever they apply.

1. Vacuum Tritium Battery

a. General Characteristics

(1) Isotope half life - 12.5 years

(2) maximum beta particle energy = 18,000 V

(3) mean energy - 6000 volts

(4) gamma ray energy - none

(5) specific power - 28 K cur/watt

(6) estimated cost - $ .50/curie

(7) range of mean beta particle - .055 mg/cm^2

b. Suggested design of a .1 watt battery

(1) structure - A (figure 4)

(2) operating voltage - 6000 volts

(3) maximum output current density (amp/in^2 curie) = 10^{-9} (experimental)

(4) collection efficiency - 10% (experimental)

(5) calculations:

(a) efficiencies

$$e_v = \frac{6000}{6000} = 1$$

$$e_i = \frac{10^{-9} \text{ amps}}{5.92 \times 10^{-9}} = 169$$?

$$e_c = 1$$

$$e_g = .95$$

$$e = e_v e_c e_i e_g = (1)(.169)(.1)(.95) = .0157$$

(b) power required

$$Po = \frac{.1}{.0157} = 6.35 \text{ watts}$$

(c) number of curies required

$$\frac{28 \times 10^3 \text{ curies}}{\text{watt}} \times 6.25 \text{ watts} = 175{,}000 \text{ curies}$$

(d) cost - $.50/curie x 175,000 curies = $87,500

(e) size - 175,000 in^2. Using 6" x 6" source configuration, overall length approximately 500".

2. Solid Dielectric Tritium Battery

a. General Characteristics:

(1) isotope half life - 12.5 years

(2) maximum beta particle energy - 18,000 V

(3) mean beta particle energy - 6000 V

(4) gamma ray energy - none

(5) specific power - 28 Kc/watt

(6) estimated cost - $.50/curie

(7) range of mean beta particle - .055 mg/cm^2

b. Suggested design of .1 watt battery

(1) structure - B (figure 5)

(2) operating voltage - 14 V

(3) maximum output current density (amp/in^2 curie) = 10^{-9} (experimental)

(4) dielectric thickness (1/2 mean range) = 1/4 micron = .025 mg/cm^2

(5) calculations

(a) efficiencies

$e_v = \frac{14}{6000} = .00238$

$e_i = .169$

$e_d = .75$

$e_g = 1$

$e = e_v e_i e_d e_g = 2 \times 10^{-3} (.169)(.75)(1) = 3.02 \times 10^{-4}$

(b) power required

$$Po = \frac{.1}{3.02} \times 10^{-4} = 3.31 \times 10^{2} = 331 \text{ watts}$$

(c) number curies required

$$28 \frac{KC}{watt} \times 331 \text{ watts} = 9.25 \times 10^{6} \text{ curies}$$

(d) cost \$ .50/curie x 9.25×10^{6} curie = $4.63\ 10^{6}$ dollars

c. Comments

(1) Efficiency too low

(2) Cost prohibitive

3. Vacuum Nickel Battery

a. General Characteristics

(1) isotope half life - 85 years

(2) maximum beta particle energy - 67,000 volts

(3) mean beta particle energy - 22,300 volts

(4) gamma ray energy - none

(5) specific power = 8.3 kilocurie/watt

(6) estimated cost - \$45/mc

(7) range of mean beta particle - .8 mg/cm^2

b. Suggested design for .1 watt battery

(1) Structure - A (Figure 4)

(2) operating voltage - 20,000 V

(3) current efficiency - 3% (experimental)

(4) collection efficiency - 10% (estimate)

(5) calculations

(a) efficiencies

$e_v = \frac{20,000}{22,300} = .91$

$e_I = .03$

$e_c = .10$

$e_g = .95$

$e = e_v e_I e_c e_g = (.91)(.95)(.1)(.03) = .00259$

(b) Power required

$Po = \frac{.1}{.0026} = \frac{100}{2.6} = 38.6$ watts

(c) number of curies required

$8.3 \times 10^3 \frac{\text{curies}}{\text{watt}} \times 38.6 \text{ watts} = 320,000 \text{ curies}$

(d) Cost 3.20×10^5 mc x $\frac{\$.45}{\text{mc}} = \underline{\$1.44 \times 10^7}$ for isotope

c. Comments

(1) costs prohibitive

(2) delivery uncertain

4. Krypton solid dielectric battery

a. General Characteristics

(1) Isotope half life - 10.27 years

(2) maximum beta particle energy - .695 (99%)Mev

(3) Mean beta particle energy - .232 Mev

(4) Gamma ray energy - .51 Mev (.65%)

(5) specific power - .77 kilocuries/watt

(6) estimated cost - $15/curie

(7) range of mean beta particle = 51 mg/cm^2 = 45 cm air

(8) activity - 100 mc/cc

(9) density - d_{kr} = .00375 gm/cc

b. Suggested Design of .1 watt krypton battery

(1) structure - C (Figure 6)

(2) operating voltage - 9000 volts

(3) range of mean beta particle in Kr = Ra (d_a/d_{kr}) = 45 $\frac{(1.293)}{3.75)}$ = 15.7 cm

(4) dielectric thickness - 10 mils (polystyrene)

(5) calculations

(a) efficiencies (using 8 atmospheres Kr pressure, and 8" x 8" plates separated by 0.5 cm.)

$e_v = \frac{9000}{232,000} = .039$

$e_i = 1 - (1/2)\frac{8 \times 3.75 \times 1/2}{51} = .187 = 813$

e_d = .75 (for 10 mil polystyrene)

e_g = .95

$e = e_v e_i e_d e_g = (.039)(.813)(.75)(.95) = .0226$

(b) power required

$Po = \frac{.1}{.0226} = 4.43$ watts

(c) curies required

$.77 \frac{Kc}{W} \times 4.43 = 3.42$ Kc

(d) cost

\$15/curie x 3,420 = \$51,200

(e) Size - volume of space containing krypton = 206 cc/section of eight atmospheres. We have 800 mc/cc or 1.648×10^5 mc/section (.165 K curie); therefore, the number of sections needed are

$\frac{3.42}{.165} = 20.7 = 21$ sections (8" x 8" x .2")

The size of the battery will approximate 8" x 8" x 4.5".

c. Comments

(1) price is a bit lower

(2) size is reasonable

(3) radiation is high R/hr at 1 ft = 115)

5. Promethium (147) - Solid Dielectric Battery

a. General Characteristics

(1) Isotope half life - 2.6 years

(2) maximum beta particle energy - .223 Mev

(3) Mean beta particle energy - 73,000 volts

(4) gamma ray energy - none

(5) specific power - 2.3 kilocurie/watt

(6) estimated cost - $3.25/curie (for less than 20,000 curies)
$2.50/curie from 20,000 curies to 100,000 curies

(7) range of mean beta particle - 7.2 mg/cm^2

(8) density - 8 gm/cm^3

b. Suggested design of .1 watt battery

(1) structure D (figure 7)

(2) operating voltage - 2,000 volts

(3) thickness of the promethium 1/2 mean range) = 3.5 mg/cm^2

(4) dielectric - polystyrene (2 mils)

(5) calculations

(a) efficiencies

$$e_v = \frac{2000}{73000} = .0275$$

$$e_i = 1 - 1/2 = .5$$

$e_c = 1/2(10/7.2) = .31$

$e_g = 1$

$e = e_c e_g = .0046$

(b) power required

$Po = \frac{.1}{.0046} = 22$ watts plus 1 watt for decay correction

(c) curies required

$2.3 \frac{\text{Kilo curies}}{\text{watt}} \times 23.0 \text{ watts} = 52.8$ kilocuries

(d) cost

52.8×10^3 curies x \$2.50/curie = \$132,000

(e) size

For 52.8 ~~curies~~ $\times 10^3$ curies of promethium, we need 700 grams (Pm yield 13.2 gm/Kcurie). Using 8" x 8" sheet (20 cm x 20 cm) with mean range thickness we have 1.4 gm/sheet. Therefore, we need 500 sheets. The battery size will be approximately 8" x 8" x 2.5".

c. Comments

(1) cost high

(2) availability questionable

(3) Low external radiation

6. Thulium 170 - Solid dielectric Battery

a. General Characteristics

(1) Isotope half life - 130 days

(2) Maximum beta particle energy - .97 (90%) MEV
.88 (10%)

(3) Mean beta particle energy - .32 Mev

(4) Gamma ray energy - .084 (22%)

(5) specific power - .532 kilocurie/watt

(6) estimated cost - uncertain

(7) range of mean beta particle - 80 mg/cm^2

(8) density - 9 gm/cm^3

b. Suggested design .1 watt battery

(1) structure - D (Figure 7)

(2) operating voltage - 20,000 volts

(3) thickness of thulium (1/4 mean range) = .02 mm

(4) thickness of polystyrene - 20 mils (50 mg/cm^2)

(5) calculations

(a) efficiencies

$$e_v = \frac{20,000}{320,000} = .0625$$

$e_i = 3/4$

$e_d = 3/8$

$e_g = 1$

$e = (.0625)(.75)(.375)(1) = .018$

(b) power required

$$Po = \frac{.1}{.018} = 5.5 \text{ watts}$$

(c) number of curies required

$$.532 \frac{\text{kilocuries}}{\text{watt}} \times 5.5 \text{ watts} = 2.95 \text{ kilocuries}$$

(d) Cost - at MTR the cost for irradiation in a flux ϕ = 10^{14} n/s cm^2 is $55/10 days/in. Therefore, the cost for six months (200 days) is $3,300.

(e) size

For 3 kilocuries at the end of one year, 35.6 kilocuries are required at the beginning of the year. This activity will be obtained from irradiation of 44 gms (4.82 cc) of thulium for six months in a flux of 10^{14} neut/cm^2-sec

35.6 kilocuries = 66.2 watts thermal initially
= 5.53 watts thermal at one year
= .1 watt electrical at one year

The size will be a cylinder approximately 1 1/8" diameter and 3" long.

c. Comments

(1) technology unknown

(2) structure excellent

(3) cost reasonable

(4) Possibility of irradiation after assembly of battery to eliminate handling radioactive isotope (proposed by Dr. P. Murphy).

(5) External radiation = 2672 R/hr at one foot but .08" of tungsten shielding will reduce it to 2 mR/hr at one foot.

V. EXPERIMENTAL

The experimental investigations consisted of the construction and evaluation of small krypton batteries. The structures of these batteries, shown in Figures 8, 9 and 10, were brass cylinders, internally lined with polystyrene sheets, and utilizing an

insulated central terminal which served as the filling tube and anode. Two different size batteries were constructed; one with an internal volume of 1 cc. and the other of 3 cc. Quantitative measurements of the exact quantities of gas used were not taken. Resistivity tests were performed on all units before filling and those with more than 100 uua leakage at 300 volts were rejected. Subsequent to filling, output currents as high as 500 uua were observed. Tests on the larger battery continued for three weeks but the sporadic nature of the readings lead to no definite conclusions. It was found necessary to dehumidify the testing area in order to eliminate large fluctuations in our measurements. After one month, the larger battery (K2) showed a constant current of 400 uua against a bucking voltage of 900 volts. The experimental arrangement used is shown in Figure 11. This batterycharged an electrostatic voltmeter to 1000 volts.

A vacuum system was designed and constructed for the filling of the krypton batteries. This system is shown in Figure 13, 14 and 15. A lead-shielded container was used to limit the radiation hazard from the radioactive gas. (Placing the radioactive container on the vacuum system will give the experimenter an integrated dose of approximately 500 mr.) The procedure used in filling the krypton batteries was (refer to the photograph in Figure 13):

(i) All valves with the exception of A and B were open to the system

(ii) At a pressure of approximately 10^{-4} mm(hg) the valves to the diffusion pump, fore pump, and ion gauge were closed (valves C, D and E).

(iii) Valves A and then B were opened. The gas then flowed into the system and reached an equilibrium pressure.

(iv) These valves were then closed (A and B) and the battery pinched off. The time from placing the battery on the system until pinching off the tubulation was about one hour. The major portion of this time was used for the reduction of pressure from atmospheric to 10^{-4} mm. It should be mentioned that the mechanical pressure gauge was not used in the initial runs. Due to the intermittent filling schedule it was deemed unwise to create another radiation hazard with the gas which would reside in the gauge.

VI. PROPOSED FUTURE PROGRAM

A. Dielectric Studies

The successful construction of a solid dielectric battery is dependent upon the properties of the dielectric. The fabrication of a .1 watt battery will necessitate the use of kilocuries of activity over long periods of time. The effects of this intensity of radioactivity on the electrical properties of dielectrics are, on the whole, unknown. An extensive study of the changes induced by the radioactive source must be pursued. The fundamental properties to be studied for this application are

1. electrical conductivity
2. electrical breakdown
3. phyiscal degradation

Considering these, the following experiments are necessary. A large source of charged particles variable in energy and intensity must be available (electron acceleration). A sample of the dielectric to be studied will be inserted into the accelerator and the effect of the radiation studied. By varying the intensity and energy, the kilocurie radioactive source can be simulated and long term irradiation effects studied in a

relatively short time. From existing data there are indications that a threshold exists in dielectrics, such that above a certain energy large conductivity changes occur. This possible limitation must be studied in detail.

The second electrical property to be studied is that of voltage breakdown during irradiation. This test has not been performed and thus requires immediate investigation. Voltages on the order of 20,000 volts are contemplated in some battery designs and electrical integrity must be maintained for successful operation of the power source.

Three promising dielectric materials to be studied are

1. polystyrene
2. quartz
3. mica

B. Thulium Battery

Initial design calculations show the economic advantage of a thulium battery. One approach considered reasonable is to construct a simple small cell and have it irradiated at the Brookhaven National Laboratory critical facility. This cell would give data which could be extrapolated to a full scale model and at the same time provide an opportunity to become familiar with the technical problems arising.

C. Voltage Transformer

The construction of a DC to DC voltage transformer is an essential phase of this study. The use of such a device for converting from approximately 20,000 volts to 14 volts is required for the utilization of the radioactive energy with standard electronic components. Work on the conversion of these high voltages has been sparse.

A method which indicates some promise is the use of a relaxation oscillator of special design. Further investigation on this phase of the overall problem will proceed concurrently with other research of interest to this project.

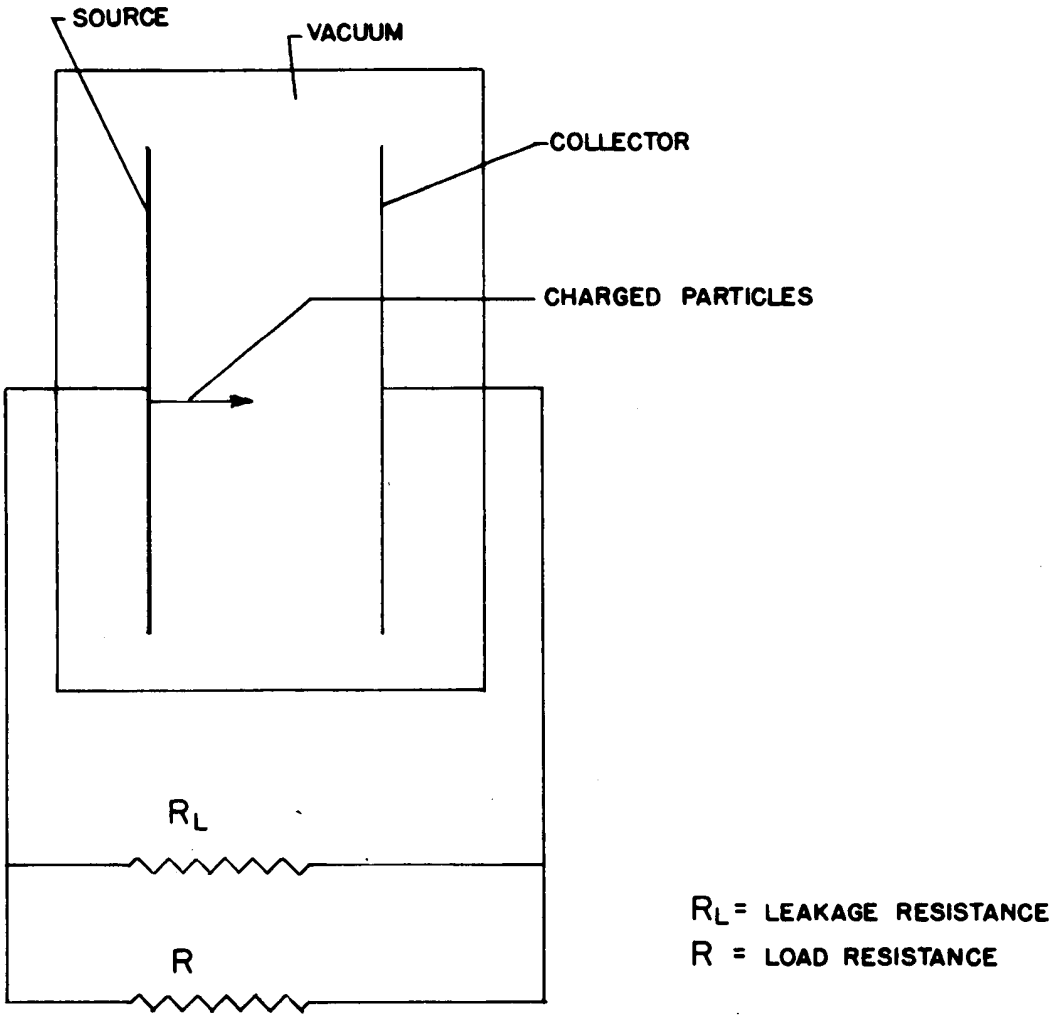
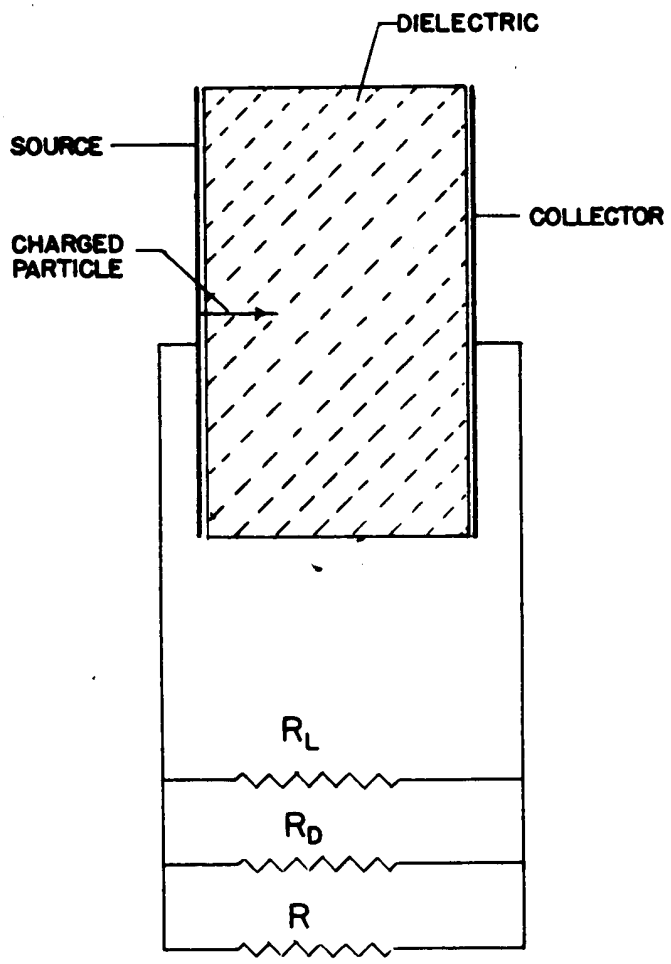


FIG I-1 VACUUM DIELECTRIC BATTERY



R_L = LEAKAGE RESISTANCE

R_D = DIELECTRIC RESISTANCE

R = LOAD RESISTANCE

FIG 1-2 SOLID DIELECTRIC BATTERY

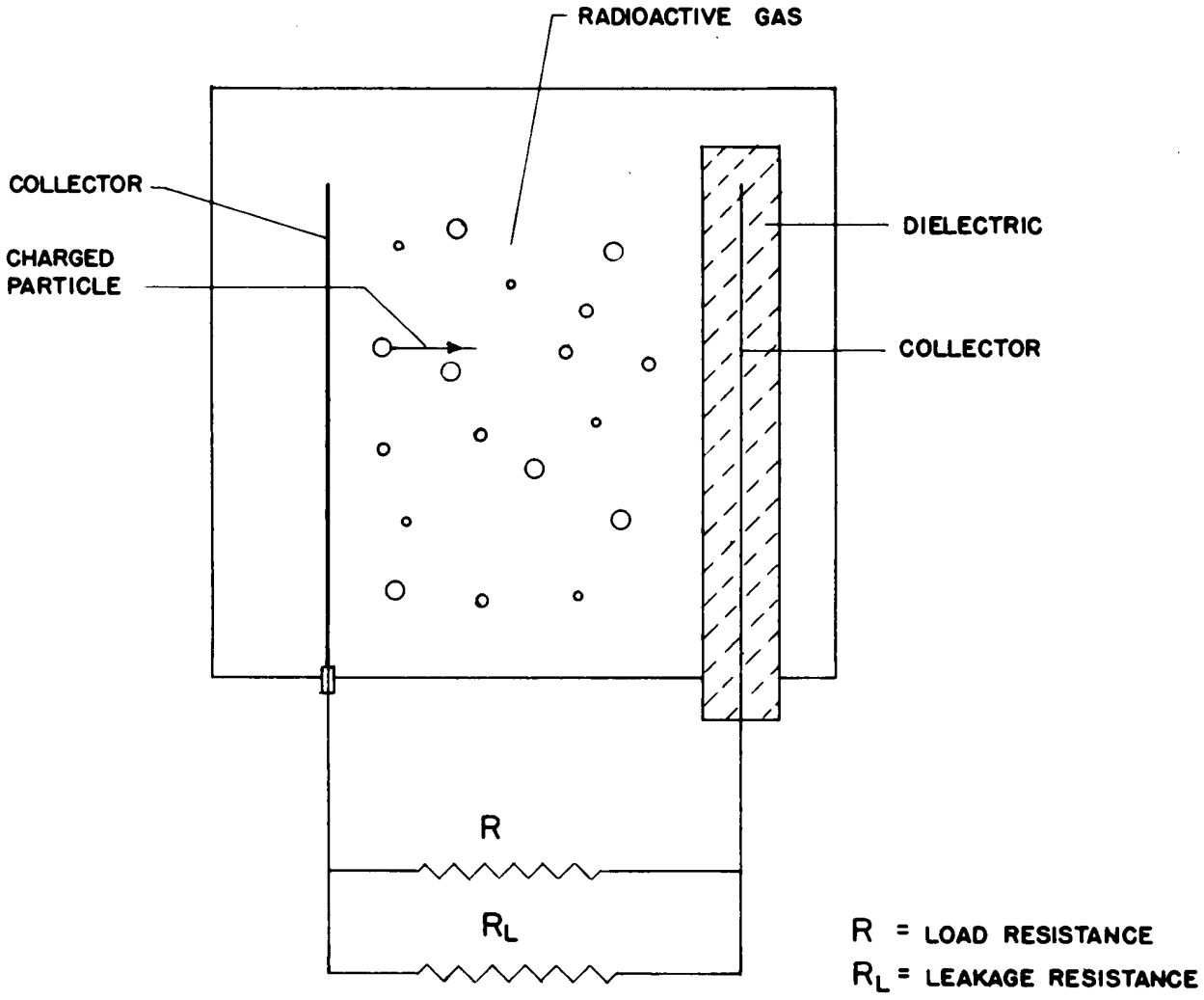


FIG I-3 SOLID DIELECTRIC BATTERY WITH GAS SOURCE

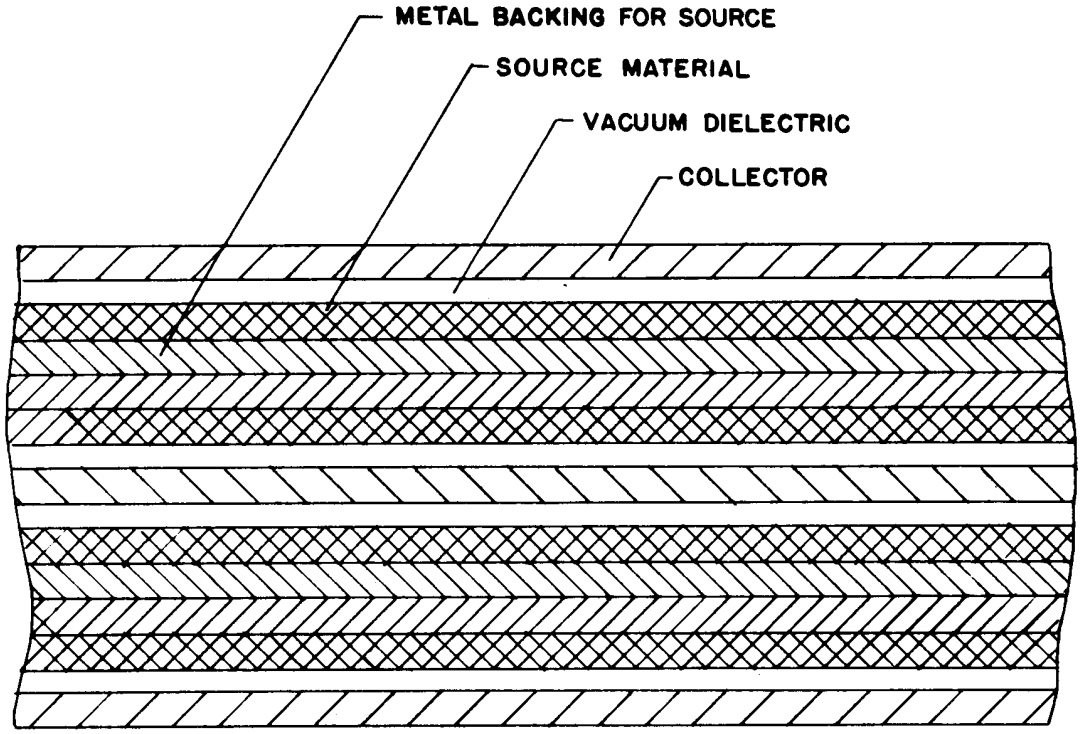


FIG I-4 STRUCTURE A

DR. NO. 561

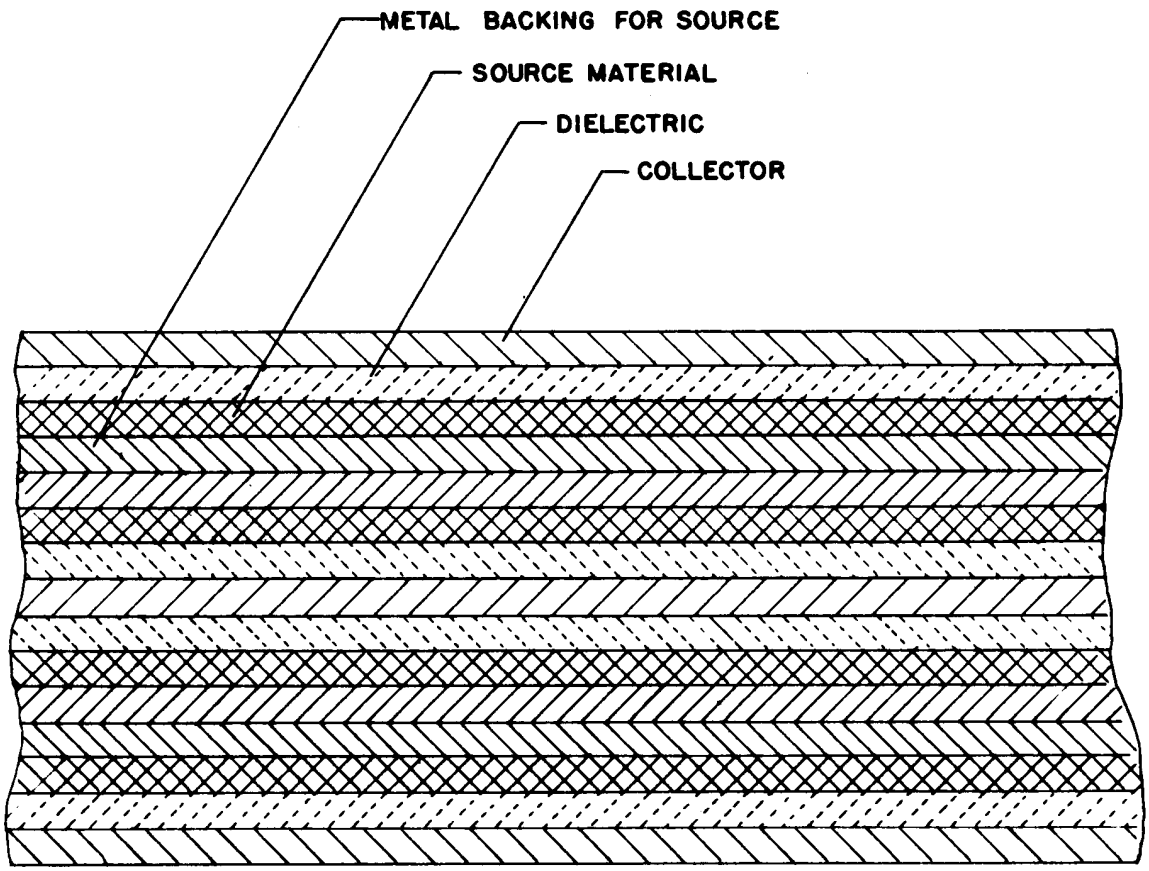
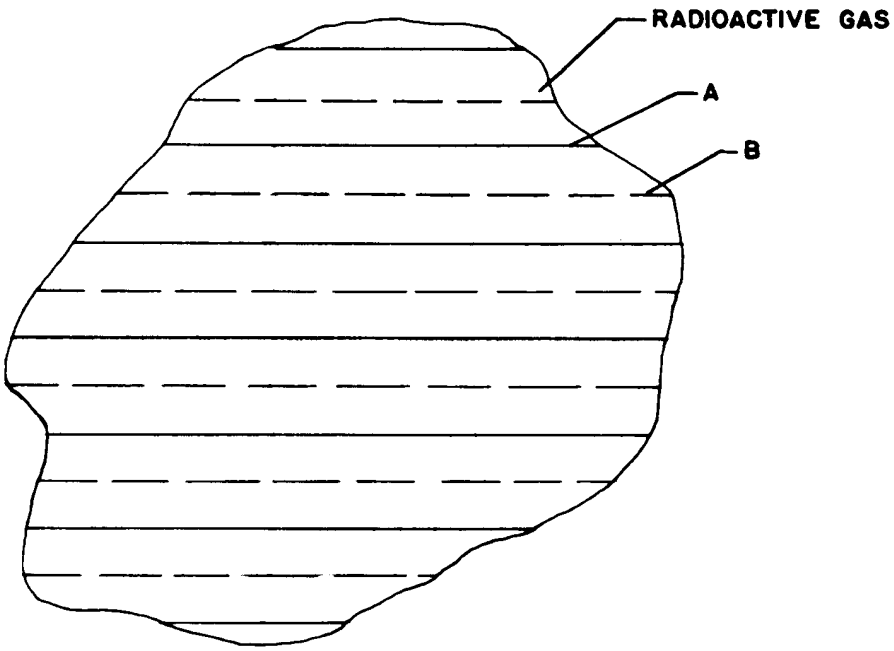


FIG I-5 STRUCTURE B

DR. NO. 562



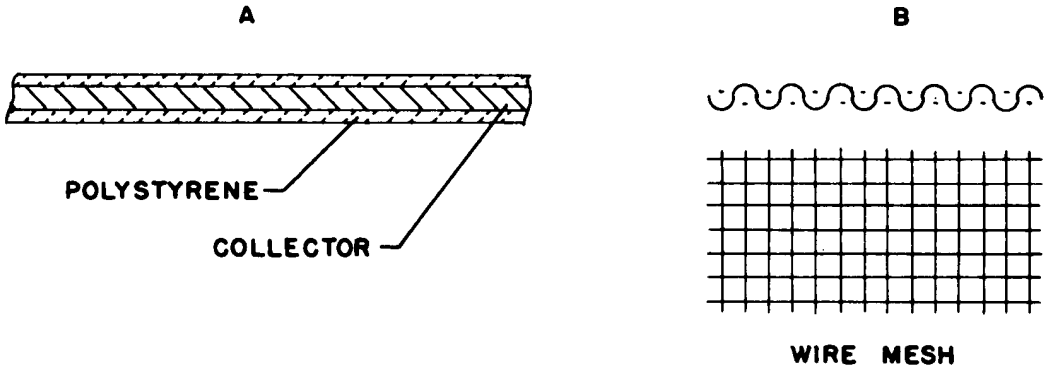


FIG 1-6 STRUCTURE C

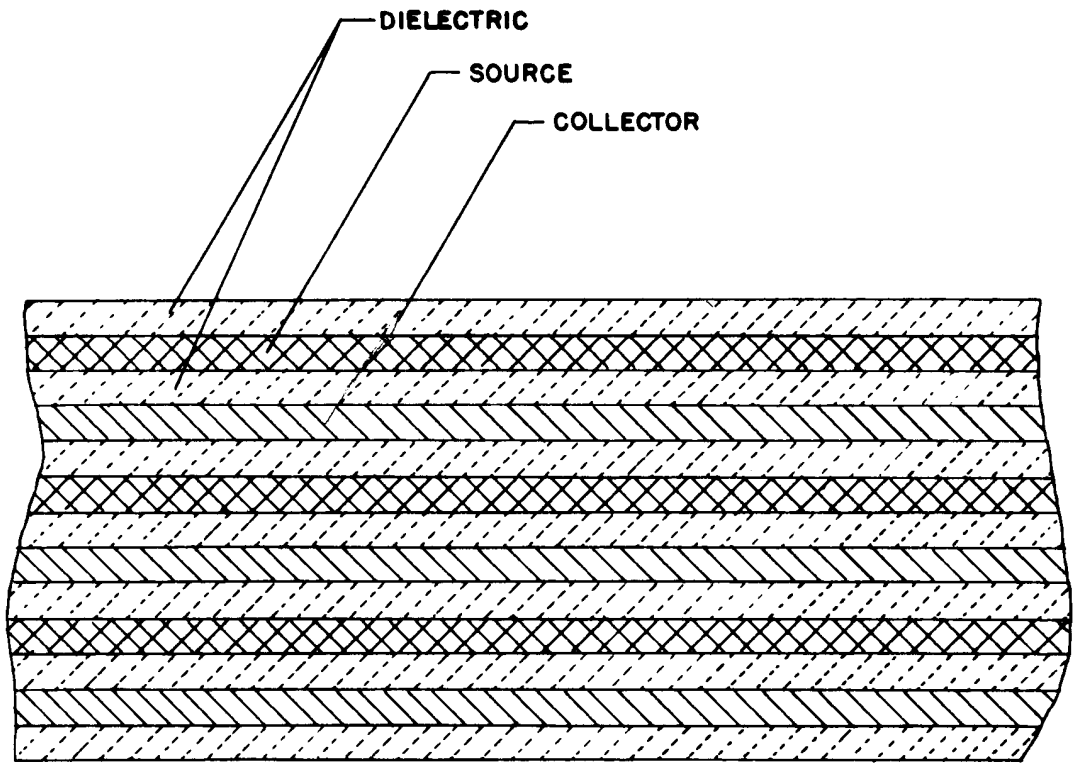


FIG 1-7 STRUCTURE D

SECRET

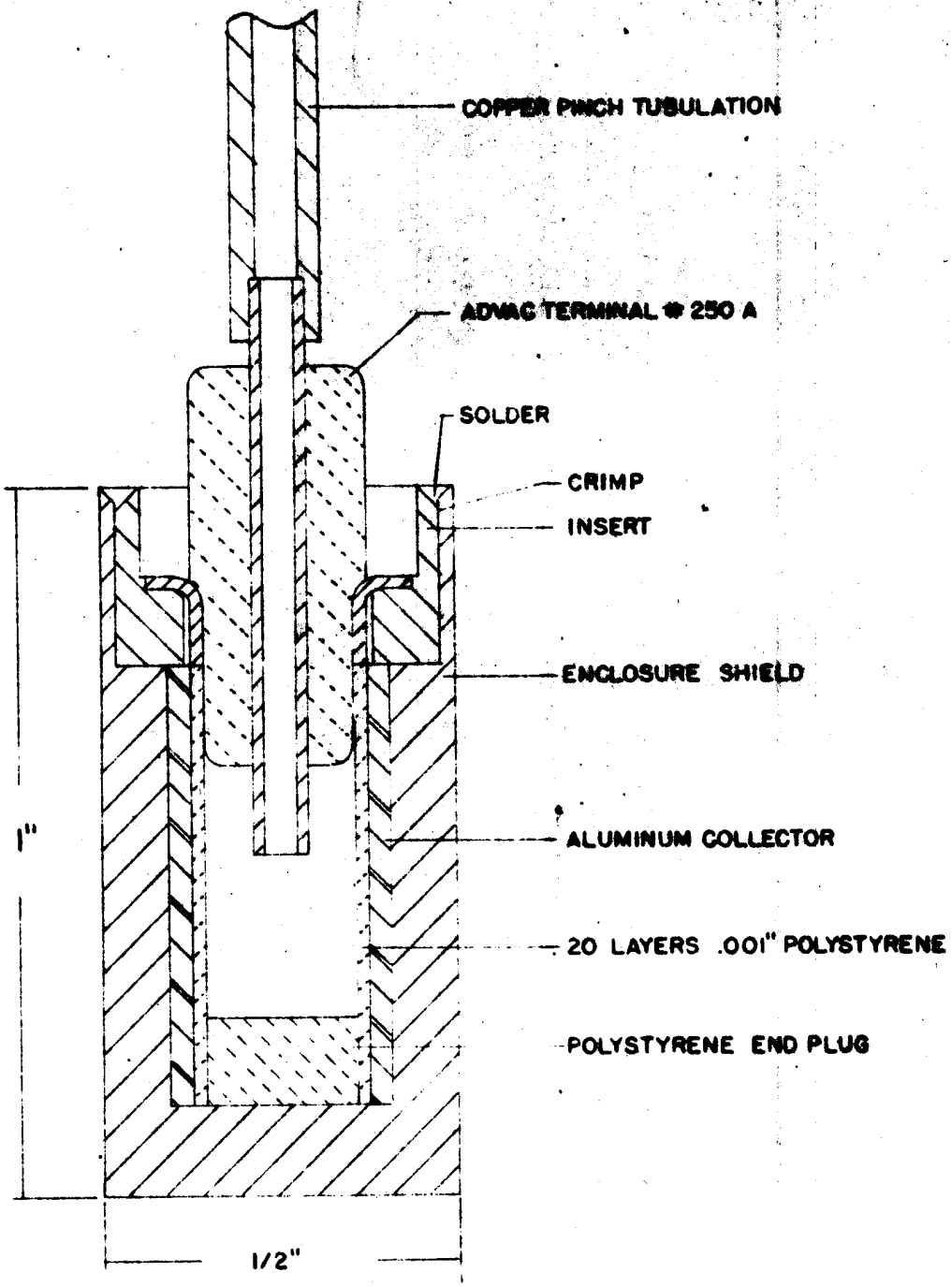


FIG 1-8 MODEL K-1 KRYPTON BATTERY

SECRET

SCALE 4"=1"
DR.NO. 485
6/6/58

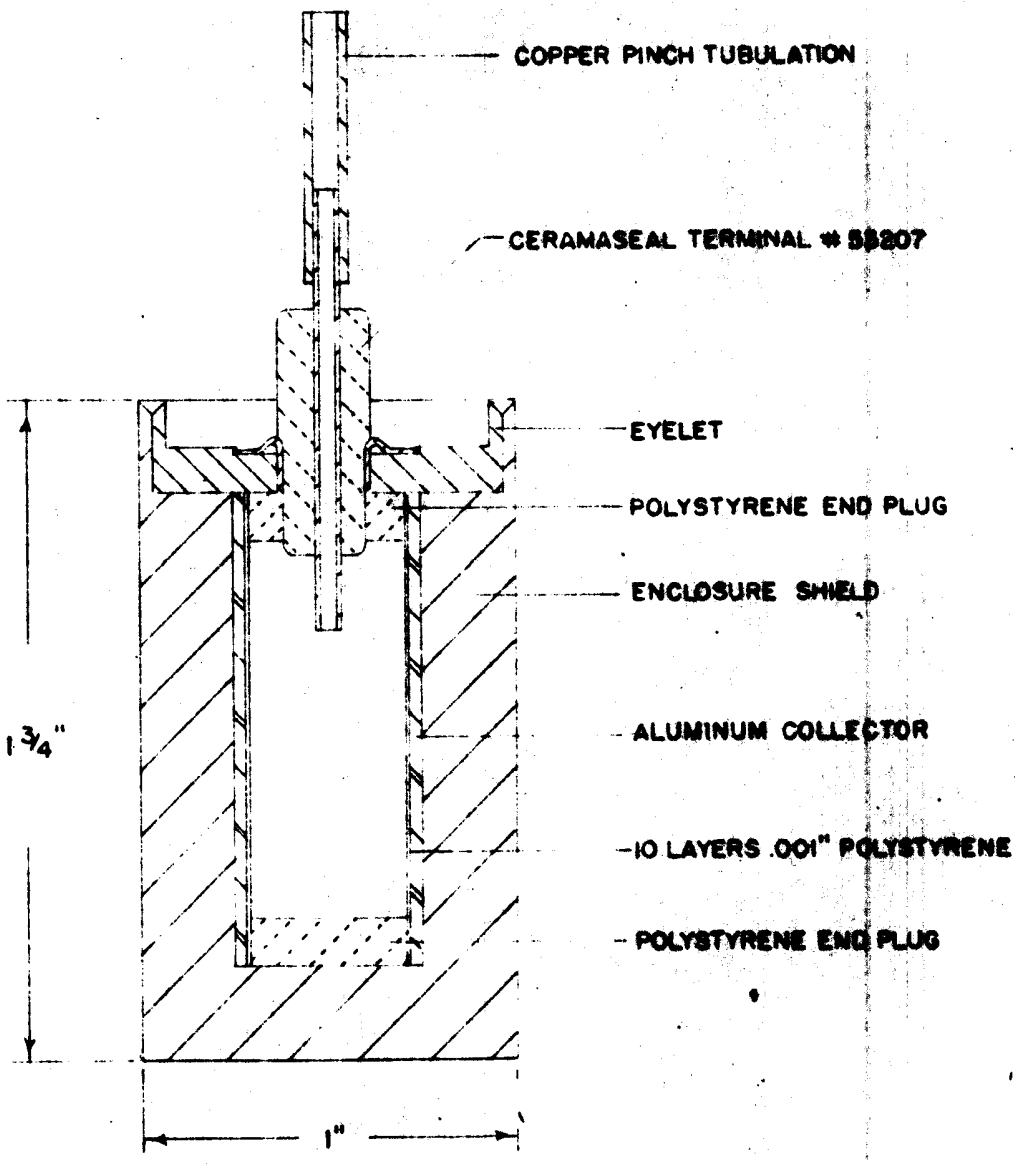


FIG 1-9 MODEL K-2 KRYPTON BATTERY

SCALE 2"=1"
DR.NO 432
5/19/58

JHC

SECRET

DR.NO. 564

FIG I-10 EXPLODED VIEW OF KRYPTON BATTERY

SECRET

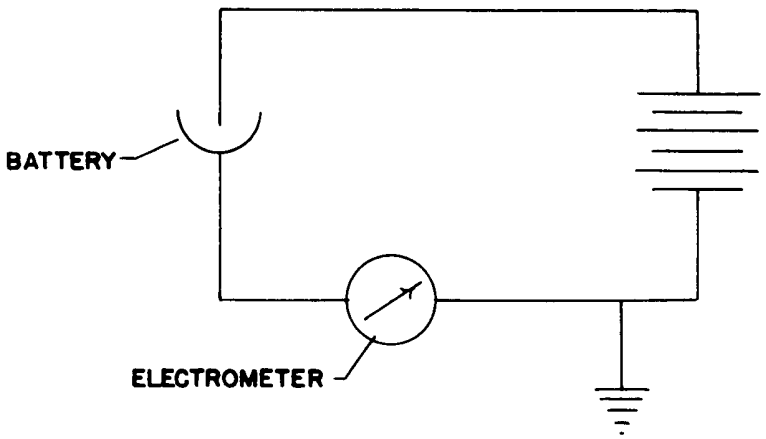


FIG I-II EXPERIMENTAL MEASUREMENT CIRCUIT

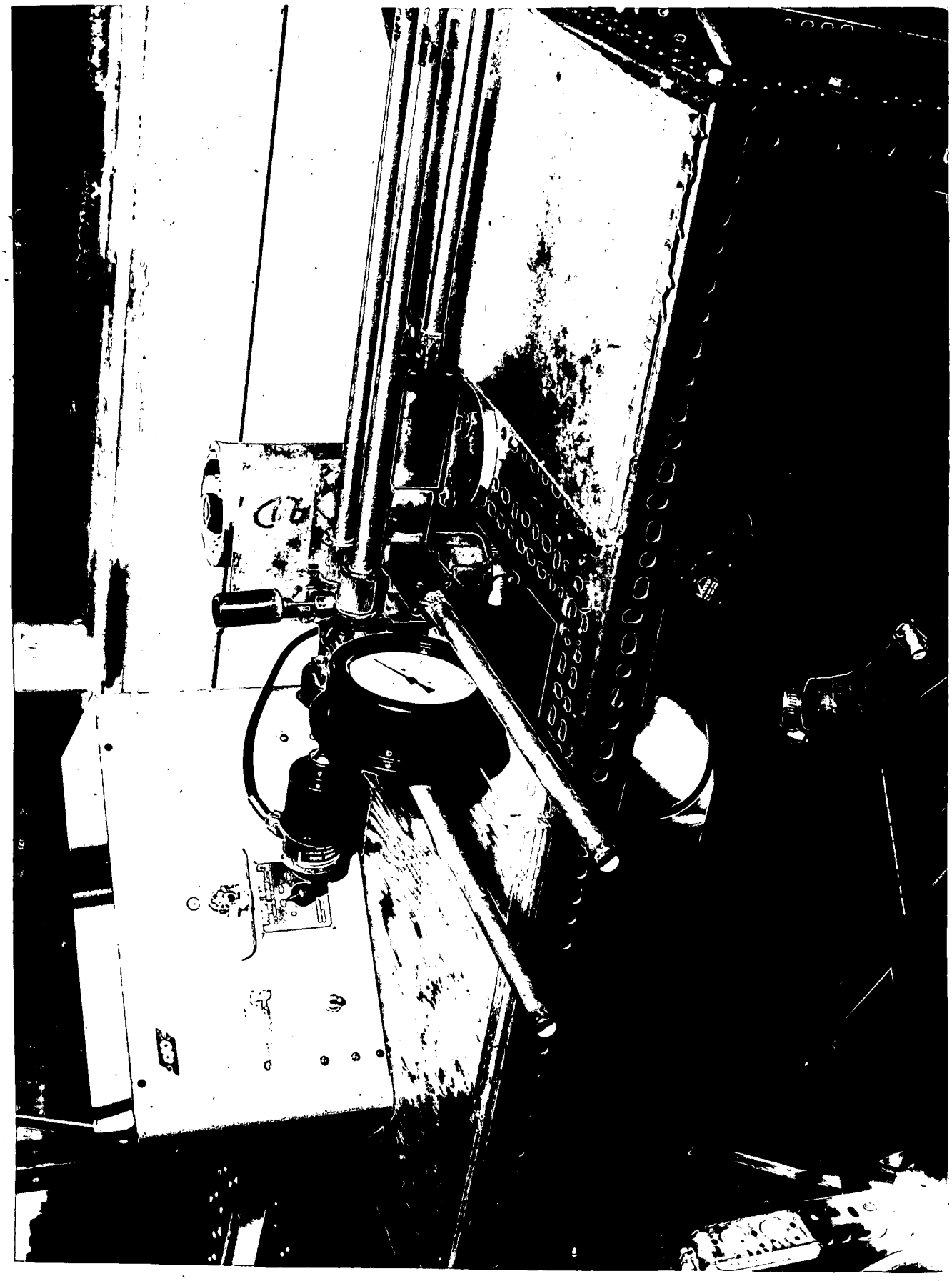


FIG I-13 KRYPTON FILLING SYSTEM

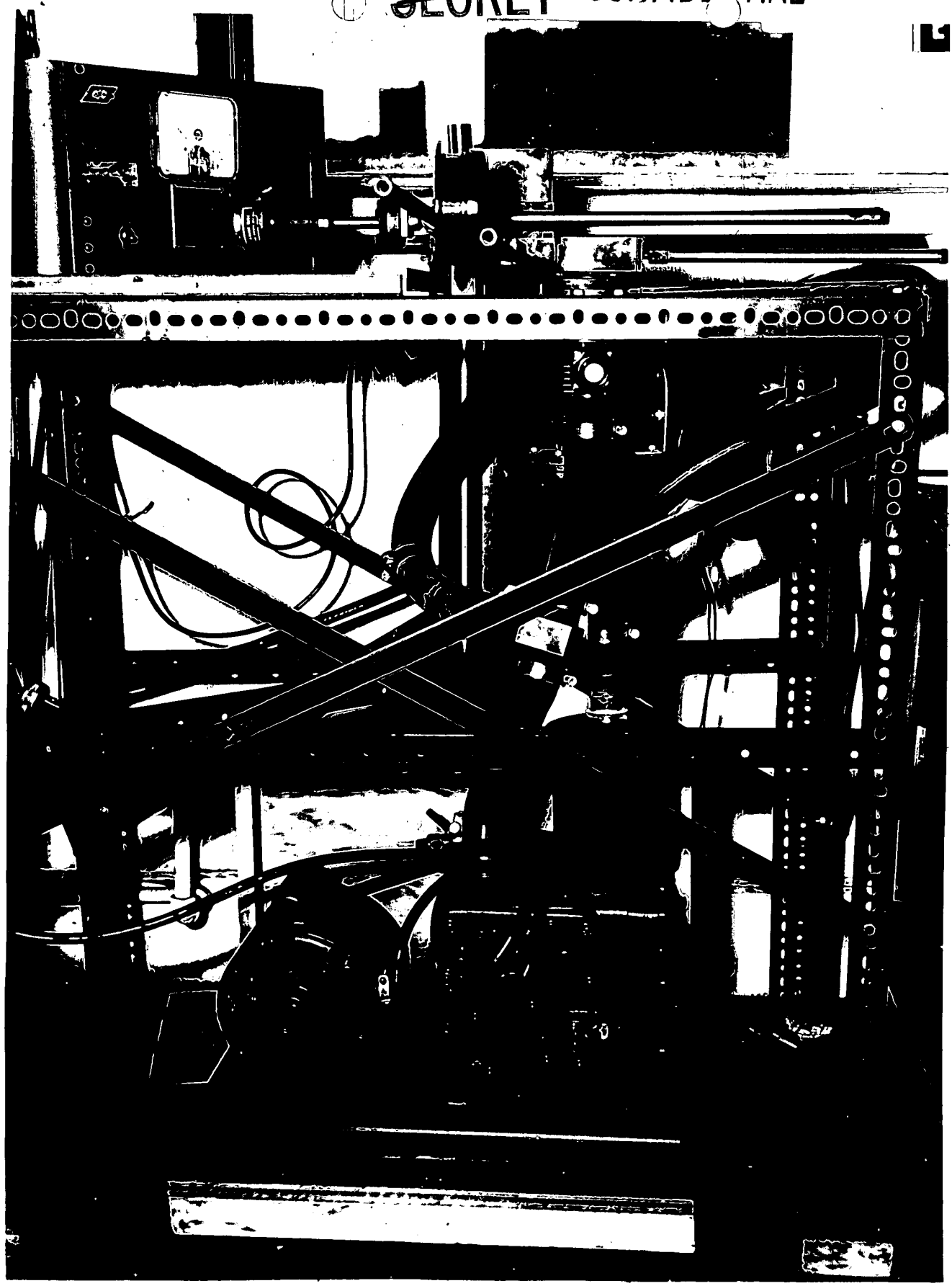


FIG I-14 KRYPTON FILLING SYSTEM

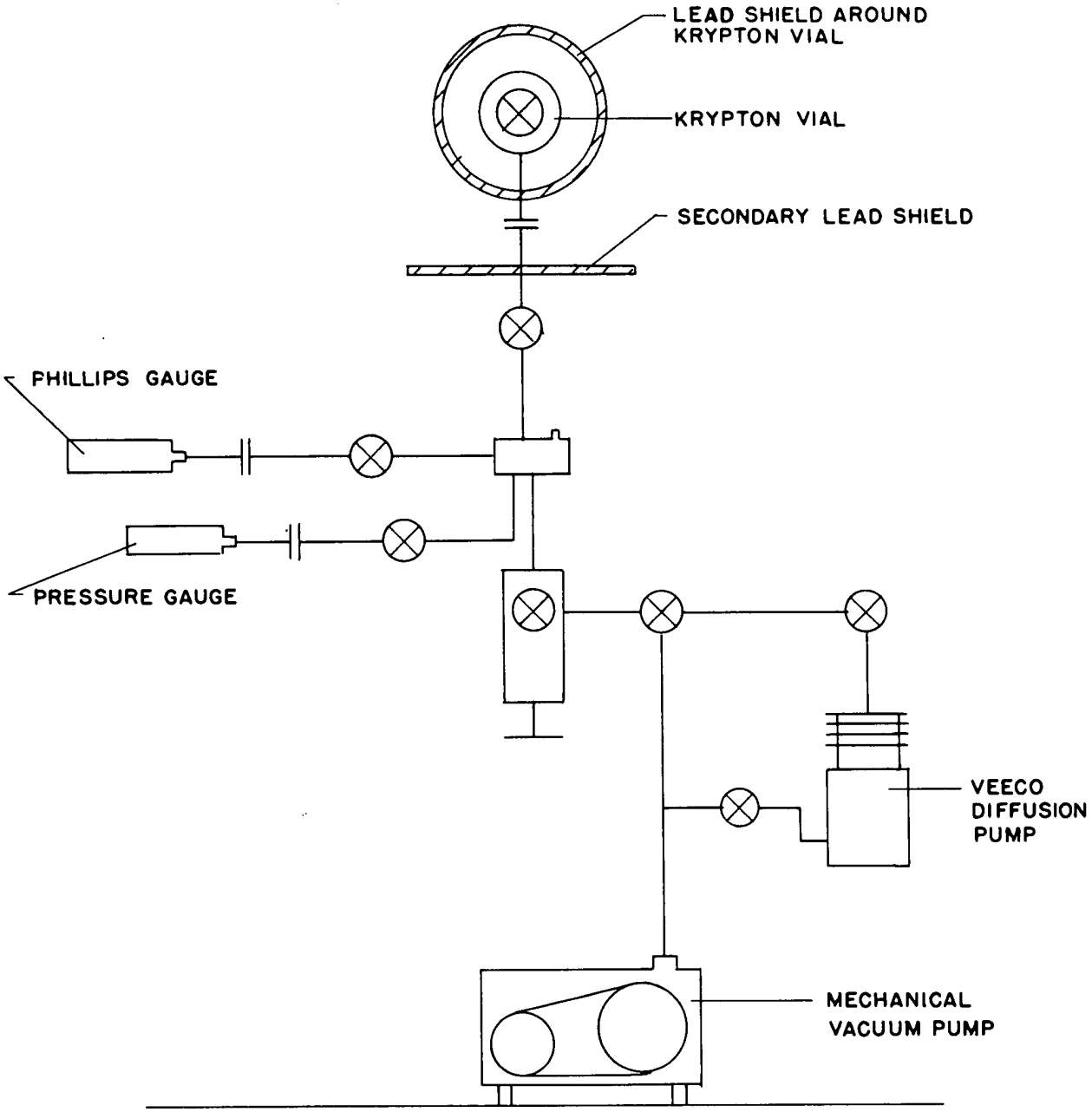


FIG I-15
SCHEMATIC DIAGRAM OF KRYPTON SYSTEM NO. I